DESCRIPTION

OPTIMISING BRIGHTNESS CONTROL IN A 3D IMAGE DISPLAY DEVICE

The present invention relates to display devices, and in particular to display devices adapted to display three dimensional or stereoscopic images.

The generation of three-dimensional images generally requires that a display device is capable of providing a different view to the left and the right eye of a user of the display device. This can be achieved by providing a separate image directly to each eye of the user by use of specially constructed goggles. In one example, a display provides alternating left and right views in a time sequential manner, which views are admitted to a corresponding eye of the viewer by synchronised viewing goggles.

In another example, such as that described in US 6,172,807, time sequential synchronisation of left and right eye views is provided by way of a spatial modulation element in the form of an LCD panel which alternately occludes left and right eye views of a display using parallax. In order to correctly occlude left and right eye views, the system of US '807 has to constantly track the position of the viewer relative to the display device.

In contradistinction, the present invention relates to classes of display devices where different views of an image can be seen according to the viewing angle relative to a single display panel without necessarily requiring tracking of user position. Hereinafter, these will be referred to generally as 3D display devices.

One known class of such 3D display devices is the liquid crystal display in which the parallax barrier approach is implemented. Such a system is illustrated in figure 1.

With reference to figure 1, a display device 100 of the parallax barrier type comprises a back panel 11 that provides a plurality of discrete light sources. As shown, the back panel 11 may be formed by way of an areal light

source 12 (such as a photoluminescent panel) covered with an opaque mask or barrier layer 13 having a plurality of slits 14a to 14d distributed across its surface. Each of the slits 14 then acts as a line source of light.

A liquid crystal display panel (LCD) 15 comprises a plurality of pixels (eg. numbered 1 to 10 in figure 1) which are separately addressable by electrical signals according to known techniques in order to vary their respective light transmission characteristics. The back panel 11 is closely positioned with respect to the LCD panel 15 such that each of the line sources 14 of light corresponds to a group 16 of pixels. For example, pixels 1 to 5 shown as group 16_1 correspond to slit 14a, pixels 6 to 10 shown as group 16_2 correspond to slit 14b, etc.

Each pixel of a group 16 of pixels corresponds to one view V of a plurality of possible views (V_{-2}, V_{-1}, V_0, V_1, V_2) of an image such that the respective line source 14a can be viewed through one of the pixels 1 to 5 corresponding to that view. The number of pixels in each group 16 determines the number of views of an image present, which is five in the arrangement shown. The larger the number of views, the more realistic the 3D effect becomes and the more oblique viewing angles are provided.

Throughout the present specification, we shall refer to the 'image' being displayed as the overall image being generated by all pixels in the display panel, which image is made up of a plurality of 'views' as determined by the particular viewing angle.

A problem exists with this prior art arrangement. The brightness of any given discrete light source 14 as perceived by the viewer will be a function of the size of the pixel lying between the light source and the viewer in a direction orthogonal to the light beam. In other words, the angular size of view of the light source 14a as viewed through pixel 3 of figure 1 is greater than the angular size of view of light source 14a as viewed through pixel 5.

Therefore, the perceived intensity of the viewed source will be a function of viewing angle. This results in a dimmer image when viewed at more oblique angles, and therefore unwanted intensity artefacts when observing the different views of the image.

It is an object of the present invention to overcome or mitigate the unwanted intensity artefacts in a display device for displaying three dimensional images in which different views of the image are displayed according to the viewing angle.

According to one aspect, the present invention provides a display device for displaying a three dimensional image such that different views are displayed according to the viewing angle, the display device including:

a display panel having a plurality of separately addressable pixels for displaying said image, the pixels being grouped such that different pixels in a group correspond to different views of the image, each pixel in a group being positioned relative to a respective discrete light source;

a display driver for controlling an optical characteristic of each pixel to generate an image according to received image data; and

an intensity compensation device for further controlling said optical characteristic of pixels within a group to compensate for an angular size of view, of the respective light source, via said pixels.

According to another aspect, the present invention provides a method for displaying a three dimensional image on a display device such that different views of the image are displayed according to the viewing angle, the method comprising the steps of:

processing image data to form pixel intensity data values for each one of a plurality of separately addressable pixels in display panel, the pixels being grouped such that different pixels in a group correspond to different views of the image, and each pixel in a group being positioned relative to a respective discrete light source, the pixel intensity data values each for controlling an optical characteristic of a respective pixel to generate the image;

applying intensity correction values to at least some pixel data values within each group to compensate for an angular size of view, of the respective light source, via said pixels; and

using the corrected pixel data values to drive pixels of the display panel to generate said image.

Embodiments of the present invention will now be described by way of example and with reference to the accompanying drawings in which:

Figure 1 shows a schematic cross-sectional view of an existing design of LCD device that uses the parallax barrier approach to display three dimensional images;

Figure 2 shows a schematic cross-sectional diagram useful in illustrating the geometry of a parallax barrier LCD device;

Figure 3 shows a schematic diagram illustrating the angular width of each view of a light source as determined by left and right edges of pixels through which the light source is viewed;

Figure 4 shows a graph of normalised brightness as a function of pixel number for a group of pixels providing different views of an image;

Figure 5 shows a graph of brightness correction factors to be applied to each pixel of a group of pixels providing different views of an image;

Figure 6 shows a graph of width of view and angular location as a function of view number;

Figure 7 shows a schematic block diagram of a display device according to embodiments of the present invention;

Figure 8 shows an embodiment of the invention utilising a lenticular array;

Figure 9 shows an alternative form of light source suitable for use with the display device; and

Figure 10 shows a graph of viewing angle properties of a conventional liquid crystal display panel useful in illustrating display optimisation principles in accordance with the present invention.

With reference to figure 1, the basic function of a parallax barrier type, three dimensional image display device has already been described. A similar structure of display panel 15 and back panel 11 illumination source may be

used in the preferred embodiment of the invention. However, it will be recognised that other configurations may be used as will become evident hereinafter.

In general, the invention uses a display panel 15 having a plurality of separately addressable pixels 1...10, in which the pixels are grouped so that the different pixels 1...5 or 6...10 respectively in a group 16_1 and 16_2 correspond to different views of the image. The display panel 15 may be any suitable electro-optical device in which an optical characteristic of each pixel can be varied according to an electrical control signal to generate an image. Preferably the display panel is a liquid crystal display.

An illumination source having a plurality of discrete light sources 14a ... 14d, so that each group 16 of pixels is positioned to receive light from a respective one of the light sources, is preferably provided. This may be by way of the areal light source 12 and mask 13 arrangement of figure 1, but could also be provided by way of a pixellated light source providing light sources 14 as lines of pixels, individual pixels or blocks of pixels.

Still further, the plurality of discrete light sources could be virtual light sources provided by way of a backlight and lens array (e.g. a lenticular sheet array) providing a series of high intensity light spots. Such an arrangement is illustrated in figure 9. A display device 80 includes an LCD panel 75, areal light source 72 and a lens array 71. The lens array focuses light from the areal source 72 into a plurality of discrete focal points 73 just outside the plane of the LCD panel so that each illuminates a plurality of pixels in the LCD panel, similar to that described in connection with figure 1.

Part of a group of pixels in the display panel 15 is shown in figure 2. A light source 14 of width w corresponds with, and can be viewed through, a group of pixels 0...7 at respective viewing angles ϕ_0, ϕ_1, ... ϕ_7 relative to the normal of the plane of the display panel. It will be understood that only approximately half of the pixel group 16 is shown, a further seven pixels being present to the left of pixel 0 to complete the pixel group 16.

Each pixel has a width p_0, p_1, ... p_7. Preferably, widths p_0...p_7 are equal, but they could vary in order to compensate to a certain extent for the angle of

incidence of light passing therethrough. The distance between the back panel illumination source 14 and the display panel 15 is shown as h. In a preferred display device, h = 2.3 mm, p_0 = 200 microns, and w = 50 microns although these values may be varied significantly.

Figure 3 shows that the angular size $\Delta\phi$ of the viewing cone of each view V_0, V_1, V_2, V_3, V_4 becomes smaller for higher n, where n is the pixel number counting from the pixel 0 that is centred over the light source 14 (see figure 2). This means that the brightness of each of the n views becomes less for higher values of n, assuming that the light source 14 is an isotropic emitter. This would normally be the case at least to the extend of angle subtended by the group 16 of pixels corresponding to the relevant light source 14. The observer will therefore experience a lower brightness for the more oblique views (e.g. V_4, V_3) than for the orthogonal view V_0. This results in some undesirable artefacts when observing the different views of the image being displayed.

The angular position ϕ_n of a view n is given by $\phi_n = \arctan(np_0 / h)$. This assumes that $p_n = p_0$ for all n (constant pixel width) such that $x_n = p_0 / 2 + np_0$. This would be the case for most LCD panels, but panels having different pixel sizes could be accommodated by suitable changes. The first view ϕ_1 at inter-eye angle $\Delta\phi_{eye}$ is given as $\phi_1 = \arctan(p_0 / h)$. The angular distance $\phi_{n+1} - \phi_n$ between neighbouring views is not constant. The values of $\Delta\phi$ and ϕ_n as a function of view number n are illustrated in figure 6 respectively as curves 31, 32.

The expression for $\Delta\phi$ is given by:

$$\Delta\phi = \arctan\{[(n + 0.5)\, p_0 + 0.5 * w] / h\} - \arctan\{[(n - 0.5)\, p_0 - 0.5 * w] / h\}$$

The number $\Delta\phi$ determines the brightness of each view. If the light source 14 is an isotropic emitter, emitting equal intensity in all (relevant) directions, the brightness scales linearly with the angle each view subtends. If

the brightness of view 0 is normalised to 1, then the brightness for each view n is given by the expression:

$$(\text{brightness view})_n = \Delta\phi_n / \Delta\phi_0$$

$$= \frac{\arctan\{[(n + 0.5)\ p_0 + 0.5 * w] / h\} - \arctan\{[(n - 0.5)\ p_0 - 0.5 * w] / h\}}{2 \arctan [(p_0 + w) / 2h]}$$

This is plotted in figure 4, normalised brightness against view number, n, for h = 2.3 mm, p_0 = 200 microns, w = 50 microns. It will be appreciated that in the case of an anisotropic light source 14, adjustments could be made accordingly to determine the brightness profile as a function of n.

In accordance with one presently preferred embodiment, it is proposed to modify the driving voltages and/or current of pixels of the LCD panel to at least partially compensate for the established brightness profile. Thus, the transmission of the LCD pixels in a group are individually adjusted to compensate for the brightness of the view that the pixel creates. For 2N + 1 views (views numbered from –N to +N), we provide an intensity compensation device that controls the optical characteristic of each pixel 0...N and 0...–N in a group 16 so as to compensate for the viewing angle.

The intensity compensation device preferably substantially normalises an intensity of the light source 14 as displayed by a group 16 of pixels to that of the other pixels in the group for any given location in the display panel. The perceived intensity thereby becomes independent of the viewing angle. The intensity compensation device may take into account any degree of anisotropic behaviour of the light source 14.

Different intensity correction factors will be required for different display types (e.g. taking into account pixel size, LCD panel thickness, light source to display spacing etc) and for transmissive versus reflective displays.

In one preferred embodiment, the intensity compensation device applies a brightness correction factor f_n for the nth pixel of a total of 2N + 1 pixels (N

pixels on either side of a centre pixel $n = 0$ normal to the light source) according to the following expression:

$$f_n = (\text{brightness view})_N / (\text{brightness view})_n$$

therefore:

$$f_n = \frac{\arctan\{[(N + 0.5)\, p_0 + 0.5 * w] / h\} - \arctan\{[(N - 0.5)\, p_0 - 0.5 * w] / h\}}{\arctan\{[(n + 0.5)\, p_0 + 0.5 * w] / h\} - \arctan\{[(n - 0.5)\, p_0 - 0.5 * w] / h\}}$$

Figure 7 shows schematically exemplary embodiments of a display device 101 incorporating an intensity compensation device.

An image processor 50 receives a stream of image information including intensity pixel data for each of a plurality of views $\phi_0 \ldots \phi_7$. The image information is processed and stored into a frame buffer 51 in digital form so that it can be rendered onto a display device 53. Frame buffer 51 includes a plurality of pages 58, each page including the pixel data for a respective view, $\phi_0, \phi_1, \ldots \phi_7$.

The frame buffer 51 is accessed by a display driver 52 that provides appropriate drive voltage and/or current signals to each pixel of a display panel 53 in accordance with each of the stored values in frame store 51. As a general principle, it will be understood that the application of intensity correction values by the intensity compensation device can be applied either:

(i) by digitally modifying the image data stored in the frame store 51 to include a correction factor so that the value of drive parameter selected by the display driver 52 is suitably modified, or

(ii) by leaving the image data stored in the frame store 51 unmodified, but applying a correction factor to the output of the display driver 52.

In a first embodiment, an intensity compensation device 60 (shown in dashed outline) is provided as, for example a look-up table accessible by the image processor 50. The look-up table comprises a plurality of pages 61, 62,

63 of correction values, each page corresponding to one of the viewing angles $\phi_1 \ldots \phi_7$ to be applied to image data received by the image processor. The image processor 50 obtains appropriate corrections to the image data and stores this compensated data in frame store 51.

The expression 'correction values' in this context may include 'substitution' values or 'offset' values. In other words, for a given input pixel value x_i, the look-up tables 61 – 63 may provide a substitution value x_s (as a function of ϕ) to be stored in the frame store in place of x_i. Alternatively, for a given input pixel value x_i, the look-up tables 61 – 63 may provide an offset value x_o (as a function of ϕ) which is combined with the input value and the result $x_i + x_o$ stored in the frame store in place of x_i.

A particular advantage of this embodiment is that it can be implemented with very little, if any, change in hardware from a conventional LCD driver arrangement. The functions of the image processor 50 can be realised in software, and the functions of the intensity compensation device 60 can also be realised as a software implementation.

In a variation on this first embodiment, the compensation device 60 may operate independently of the image processor 50 upon data already stored in the frame store 51 by the image processor 50. This can be effected by using a second access port 64 to the frame store 51. The compensation device 60 in this embodiment may also be implemented as a software module, without interfering with the operation of the image processor 50 (for example, where this is a customised graphics processor). Again, the look-up tables 61 – 63 may provide a substitution value or an offset value to be implemented by the intensity compensation device.

In a second embodiment, it is recognised that the intensity compensation for each pixel drive signal could be carried out in real time in the analogue domain, i.e. by applying a correction voltage offset to each pixel signal produced by the display driver 52. Thus, in this embodiment, an intensity compensation device 70 is installed between the display driver 52 and the display panel 53 to apply specific offset voltages and/or currents to those

output by the display driver. In this arrangement, the intensity correction values may be considered as voltage and/or current offset values.

For the sake of completeness, it is also noted that a hybrid system could deploy both techniques of digital correction values applied to the frame store 51 by compensation device 60 and analogue offsets applied to the display driver outputs by compensation device 70. An appropriate contribution would be made by both, although this may be a more complicated solution. For example, analogue offsets or correction values applied by the intensity compensation device 70 might be selected to move the operation of the display panel into an appropriate portion of a transmission-voltage characteristic, while digital correction values might be selected to compensate for differences in the slope of the transmission-voltage characteristic.

It is also noted that the intensity compensation device 60 as described herein may also be applied in other forms of 3D display other than that shown in figures 1 and 2. With reference to figure 8, it will be noted that the invention can also be applied to a lenticular 3D display device 200. In this lenticular display device, a liquid crystal display panel 115 includes a plurality of pixels (a_1 to b_8 are shown) arranged in groups 116_1, 116_2, in similar manner to that in figure 1. On top of the LCD array 115 is positioned a lenticular array 120 of cylindrical lenses 121, 122. The lenticular array may include any sheet of corrugated optical material, or array of discrete or joined lenses to provide localised focusing for groups of pixels of the LCD panel.

In the arrangement shown in figure 8, the width of each lens element is chosen to be eight pixels, corresponding to an eight-view 3D display. Of course, the width of each lens element may be chosen to correspond to different numbers of pixels according to the angular resolution required. The pixels a_1 to a_8 of the LCD are imaged into the different views. For example, the light rays emitted from pixels a_2 and a_4 are shown. One sees that in the LCD substrate 116, the rays emitted by pixel a_2 propagate to a large extent obliquely with respect to the rays emitted by pixel a_4. The angle between them is, on average, approximately equal to the angle between the two views (θ).

It will be seen that in a lenticular-type 3D display device, the light rays of the different views will still travel to the liquid crystal display panel from a respective discrete light source (not shown) at different angles relative to the plane of the display. Therefore, the problem of intensity dependency on the angle still exists, and is solved by the intensity compensation device 70 as described in connection with figure 7.

It will be recognised that the invention can be applied not only to transmissive display panel types, but also to reflective display panel types. Where the display panel provides for control of reflectivity of each of a plurality of pixels, the dependence of the reflectivity on the angle of the plane of the pixel to the light source will still exist and can be corrected for using the intensity compensation device as described herein.

The invention as described above also has important implications for the optimisation of liquid crystal displays generally. The viewing angle dependence of LCD panels is known generally to be rather poor. Figure 10 illustrates how contrast and grey scale inversion depends upon viewing angle for a standard 90 degree twisted nematic (TN) transmissive LCD without compensation foil. The horizontal viewing angle is shown on the x-axis between –60 degrees and +60 degrees from the normal to the plane of the display, and the vertical viewing angle is shown on the y-axis between –60 degrees and +60 degrees from the normal to the plane of the display.

The orientations of the optical axes 90, 91 of the LCD polarisers and the optical axes 92 of the liquid crystal directors are shown in the lower part of the figure.

From figure 10, it is seen that the image quality strongly depends upon viewing angle. For the example shown in figure 10, the optimal viewing angles are represented by the diagonal line 94 running from top left to bottom right, and grey scale inversion occurs for viewing positions to the right and above the line 94.

Conventionally, for most important applications such as televisions and computer monitors, it is recognised that maximising performance for horizontal viewing directions is more important than maximising performance for vertical

viewing directions. For example, for television applications, multiple viewers of a display device will normally be arranged with their eye levels more-or-less consistent relative to the screen (i.e. with very little variation along the y-axis), but their horizontal viewing angles relative to the x-axis may vary significantly. Similarly, a user seated at a computer monitor is more likely to vary head position along the x-axis while working, than along the y-axis.

According to convention, therefore, the LCD would be rotated anticlockwise through 45 degrees from the orientation shown in figure 10, such that its polarisation axes are at approximately 45 degrees to the x- and y-axes of the display when in use. In this way, the performance of the display device is optimised for horizontal viewing angles, but is compromised for vertical viewing angles.

3D LCD displays suffer from the same problems with optimisation of viewing angle dependency in respect of x and y directions.

However, in the present invention, it is recognised that optimisation of brightness rendering can be achieved by electronic techniques in driving the display, using the described intensity compensation device 60 and/or 70 as described above.

Therefore, it is more appropriate to provide the display device with an orientation in which the inherent optical characteristics of the display panel are optimised for vertical viewing angle variations. Horizontal viewing angle variations are accommodated for and optimised using the electronic driving techniques as described herein.

Thus, in a preferred arrangement, the 3D display device described above is arranged so that, in normal use, it has the pixels within each group 16 that provide different views as a function of angle to a first axis of the display panel, and has the polarising elements of the display panel oriented so as to minimise viewing angle dependence relative to a second axis of the display, where the second axis is orthogonal to the first axis.

In a most general sense, the inherent optical characteristics of the display panel are such that viewing angle dependence is reduced or substantially minimised relative to the y-axis and the intensity compensation

device 60 and/or 70 serves to reduce or substantially minimise viewing angle dependence relative to an axis that is transverse to the y-axis. More preferably, the intensity compensation device 60 and/or 70 serves to reduce or substantially minimise viewing angle dependence relative to an axis that is orthogonal to the y-axis (i.e. the x-axis). In a most preferred device, the x-axis is defined as the horizontal axis when the display is in normal use, and the y-axis is defined as the vertical axis when the display is in normal use.

Other embodiments are intentionally within the scope of the accompanying claims.